



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>H01S</b>		A2	(11) International Publication Number: <b>WO 99/66607</b>
			(43) International Publication Date: 23 December 1999 (23.12.99)
(21) International Application Number: PCT/US99/13551 (22) International Filing Date: 16 June 1999 (16.06.99) (30) Priority Data: 60/089,426 16 Dec 98/36 mo 2n 16 June 1998 (16.06.98) US (71) Applicants (for all designated States except US): BANDWIDTH SOLUTIONS, INC. [US/US]; 2401 Hubbard Road, Ann Arbor, MI 48105 (US). THE REGENTS OF THE UNIVERSITY OF MICHIGAN [US/US]; 3003 South State Street, Ann Arbor, MI 48109 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): ISLAM, Mohammed, Nazrul [US/US]; 647 Spring Valley Drive, Ann Arbor, MI 48105 (US). ISLAM, Mohammed, Azizul [US/US]; 1408 Miner Circle, Endicott, NY 13760 (US). SLAWSON, Michael, R. [US/US]; 6260 Bannerhorn Run, Alpharetta, GA 30005 (US). (74) Agents: SYROWIK, David, R. et al.; Brooks & Kushman, 22nd floor, 1000 Town Center, Southfield, MI 48075 (US).		(81) Designated States: CA, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published Without international search report and to be republished upon receipt of that report.	

(54) Title: DISPERSION COMPENSATING AND AMPLIFYING OPTICAL ELEMENT, METHOD FOR MINIMIZING GAIN TILT AND APPARATUS FOR MINIMIZING NON-LINEAR INTERACTION BETWEEN BAND PUMPS

## (57) Abstract

An apparatus and method are described for combining optical amplification and dispersion compensation in a Raman amplifier. A Dispersion-Managing Raman Amplifier (DMRA) combines Raman amplification with dispersion compensation by selecting the length and dispersion of the gain fiber to balance the dispersion of the link. This gain fiber is also single-mode at the signal and pump wavelengths. The pumping level is adjusted to balance the losses from the gain fiber and transmission link, while the pumping configuration is selected to remain within the 3dB loss length for the pumping light. When the amplifier is split into two segments, the two segments may be joined by an isolator, a gain equalization element, and/or an optical add/drop multiplexer. For WDM transmission systems based on dispersion-shifted fiber (DSF), operation in the "violet band" between 1430-1530 nm is based on Raman amplification. By using a DMRA, a dispersion and nonlinearity managed system can be implemented. In particular, 4WM does not phase match in such a system, and modulation instability is absent in the transmission link. Furthermore, gain equalization can be added to the DMRA by cascading one or two Mach-Zehnder frequency filters. The invention also includes a method for symmetrically adding channels below and above the C-band, the gain tilt within the C-band can be minimized. Therefore, a roughly equal number of channels should be placed in the short-wavelength S-band and the long-wavelength L-band to minimize the Raman energy exchange in the C-band. Also, whereas C- and L-bands can be amplified using erbium-doped fiber amplifiers, the S-band can use either discrete or distributed Raman amplifiers. To minimize the interaction between pumps for different bands, alternate band pumps can be spatially dispersed and/or cross-polarized. The distributed Raman amplification can be achieved by pumping the transmission line with discrete laser diodes or by a Raman oscillator.

